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THE HIGGS AS A SUPERSYMMETRIC PARTNER WITH A NEW INTERPRETATION OF YUKAWA COUPLINGS

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An unconventional version of supersymmetry leads to the following highly testable predictions: (1) The Higgs boson has an R-parity of -1, so it can only be produced as one member of a pair of superpartners. (2) The only superpartners are scalar bosons, so neutralinos etc. do not exist. (3) The most likely candidate for cold dark matter is therefore a sneutrino. (4) The Higgs and other bosonic superpartners have an unconventional equation of motion. These predictions are associated with new interpretations of Yukawa couplings, supersymmetry, gauge fields, and Lorentz invariance.

The next ten years offer promise for revolutionary new discoveries in experimental high-energy physics.[1] For example, there is every reason to believe that both a Higgs boson[2−4] and supersymmetry[5−9] will be observed at either the Tevatron or the LHC. In addition, there is strong evidence for neutrino masses,[10−12] and terrestrial dark matter experiments are now beginning to approach discovery potential.[13−17] One hopes that theoretical endeavors in these areas can respond to the challenge, and provide *testable predictions* together with new fundamental insights.

Recently we proposed a theory which does have testable predictions.[18−20] It begins with a Euclidean action

$$S = \int d^D x \left[\frac{1}{2m} \partial^M \Psi^\dagger \partial_M \Psi - \mu \Psi^\dagger \Psi + \frac{1}{2} b \left(\Psi^\dagger \Psi \right)^2 \right] \tag{1}$$

where

$$\Psi = \begin{pmatrix} z_1 \\ z_2 \\ \vdots \\ z_N \end{pmatrix} \quad , \quad z = \begin{pmatrix} z_b \\ z_f \end{pmatrix} . \tag{2}$$

This action has "natural supersymmetry",[21] in the sense that the initial bosonic fields z_b and fermionic fields z_f are treated in exactly the same way. The only difference is that the z_b are ordinary complex numbers whereas the z_f are anticommuting Grassmann numbers.

There is an alternative starting point, involving a microscopic statistical picture at the Planck scale, which leads to the phenomenological action (1). Anyone interested in this picture may consult Sections 2 and 3 of Ref. 20. Here, however, we will start closer to experiment, by simply postulating (1).

This action leads to an $SO(10)$ gauge theory,[1] which contains the Standard Model of particle physics plus the familiar see-saw mechanism for small neutrino masses. The present theory also contains Einstein gravity, as an approximation which holds below the Planck scale. Although quantization initially involves a Euclidean path integral,[18] a consistent canonical formulation is also possible.[20]

In the present theory, Lorentz invariance emerges as a very good approximation at energies that are low compared to the Planck scale – or, to be more precise, for vector bosons at essentially all energies below the Planck scale and for fermions at energies that are small compared to an energy $\lambda^2 m_P c^2$. Although there are very sensitive tests of certain aspects of Lorentz invariance[19,22] – such as rotational invariance, locality, microcausality, CPT invariance, and the requirement that $k^2 = 0$ for massless particles – these aspects are unchanged in the present theory.

The present theory thus appears to be consistent with experiment and observation. The predictions to which it leads, however, are highly unconventional. Here we will emphasize the meaning of these predictions for experiments in the foreseeable future – specifically the implications regarding searches for a Higgs boson, supersymmetry, and dark matter.

According to (1), the only fundamental fermions ψ are those of an $SO(10)$ grand unified theory with three generations, and the only superpartners are a matching set of scalar bosons ϕ. (Gauge bosons A_μ will be discussed below.) These spin 1/2 fermions and spin 0 bosons have the same gauge couplings. For example, one matching set of fields is the electroweak Higgs doublet

$$\phi_h = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} \tag{3}$$

and the charge conjugate ψ_ℓ^c of the left-handed lepton doublet

$$\psi_\ell = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}. \tag{4}$$

I.e., ϕ_h is the superpartner of ψ_ℓ^c. This means that it has a lepton number of -1, and an R-parity $R = (-1)^{3(B-L)+2s} = -1$, so the physical Higgs boson can only be produced in conjunction with another scalar superpartner.

This is, of course, an eminently testable prediction. For example, at the time this paper is being written, evidence for a standard Higgs has been reported at CERN. If this "discovery" holds up, the present theory will be disconfirmed. On the other hand, if a standard Higgs continues not to be observed, as the favorable range of parameter space is further exhausted, it may be wise to consider the possibility that the Higgs has properties other than those predicted by the Standard Model or standard supersymmetry. In the present theory, the Higgs will behave in somewhat the same way as the sneutrino of standard SUSY.[23,24]

As in other grand unified theories, lepton number conservation is a very good approximation at energies that are low compared to the GUT scale of $\sim 10^{13}$ TeV. For this and other compelling reasons,[20] the effective Yukawa couplings must have

the form

$$\lambda_{eff} = \lambda_0 \phi^\dagger_{GUT}/M \tag{5}$$

where λ_0 is dimensionless and $\left\langle \phi^\dagger_{GUT}\phi_{GUT} \right\rangle \sim M^2 \sim m^2_{GUT}$.

Since all superpartners are scalar bosons, the various fermionic sparticles of standard supersymmetry do not exist. Again, this feature is highly testable. If a neutralino or chargino is seen at the Tevatron or the LHC, the present theory will have been disconfirmed.

In the present theory, fermionic partners of gauge bosons are not required because the gauge bosons are ultimately derived from scalar boson degrees of freedom. They are, in fact, excitations of a GUT Higgs field which condenses in the very early universe, and they correspond to rotations of its order parameter Ψ_s. A program for the future is to study how the initial supersymmetry at high energy, with only spin 1/2 and spin 0 fields, evolves into a lower energy supersymmetry in which spin 1 degrees of freedom replace many of the initial spin 0 degrees of freedom. One can then determine in detail whether (i) the Higgs is fully protected from a quadratic divergence of its self-energy, as in standard supersymmetry, and (ii) whether the gauge couplings α_1, α_2, and α_3 still converge to a common value at some energy $m_{GUT} \sim 10^{13}$ TeV, as they do in standard SUSY.

Since neutralinos do not exist, the most likely candidate for cold dark matter is a spin-zero WIMP – i. e., a sneutrino. This prediction should be testable in spin-dependent dark matter searches.

We conclude with a fourth unorthodox and testable feature of the present theory: The Higgs boson, and other scalar superpartners, are predicted to have an unconventional equation of motion, which will lead to an unconventional energy-momentum relation and unconventional kinematics. Specifically, Higgs fields ϕ_h have the equation of motion

$$-\left(g^{\mu\nu} D_\mu D_\nu + i\overline{m} e^\mu_\alpha \sigma^\alpha D_\mu\right)\phi_h - \mu_h^2 \phi_h + \overline{b}\left(\phi_h^\dagger \phi_h\right)\phi_h = 0. \tag{6}$$

A standard treatment[25] then gives a similar equation for the physical Higgs boson. The extra, first-order term is due to coherent rotations of the GUT-scale order parameter Ψ_s.[26]

In summary, we have presented a series of predictions which are unique to the present theory and which should be testable in the near future, at the Tevatron, at the LHC, and in dark-matter experiments: (1) The Higgs boson has an R-parity of -1, and can only be produced together with another scalar superpartner. (2) Neutralinos and other fermionic superpartners do not exist. (3) The cold dark matter consists of sneutrinos of a new kind. (4) The Higgs and other scalar superpartners have an unconventional equation of motion which will lead to unconventional kinematics for energies significantly above threshold.

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